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OPPORTUNITIES FOR SOLAR RESEARCH.¹

BY GEORGE E. HALE.

It is safe to say that every astronomer would prize an opportunity to observe any of the fixed stars from a position where its disk would appear as large as the Sun. It does not seem probable, however, that such observations of stellar phenomena can ever be made, except in the case of the Sun itself. For it should ever be borne in mind, when considering the importance of solar research, that our most intimate knowledge of stellar phenomena must be derived from solar observations. In the case of the other stars, we may determine their positions, measure their radial velocities, observe their brightness, and analyze their light, but we have no means of studying the details of their structure, which must be understood before we can advance far in the solution of the great problem of stellar development. Thus we are driven back to the Sun, and forced to the conclusion that this typical star well deserves our most serious attention, and the application of every available means of research.

One cannot but be impressed, when considering the Sun from this standpoint, with the comparative neglect of the numerous opportunities awaiting the student of solar physics. It is possible, by the application of easily available instruments, for any careful student, wherever situated, to solve solar problems of great importance. If space permitted, it could be shown that almost all of the apparatus required in such work can be constructed at very small expense. For our present purpose, however, let us assume that the observer has at his disposal one of the cœlostats so commonly employed in eclipse work. If this cœlostат has a rather thick mirror, which is frequently resilvered, it may be depended upon to serve well for solar work, provided that the mirror is shielded from sunlight during the intervals between the exposure of photographs, and that these exposures are made as short as possible. We may assume that the sunlight is reflected from the cœlostат mirror to a second plane mirror (which should

¹ Read before the Astronomical and Astrophysical Society of America, New York, December, 1906.

also be as thick as possible) and from this mirror to an objective, which should have an aperture of at least six inches and a focal length of from forty to sixty feet. In place of this objective, a concave mirror, of similar aperture and focal length, may be employed. This apparatus will furnish the necessary means of forming a fixed solar image, of large diameter, within a laboratory, where accessory apparatus can be mounted. Let us now consider briefly some of the investigations that can be undertaken.

DIRECT PHOTOGRAPHY.

The routine photographic work, done under the direction of the Greenwich Observatory, provides ample material for the study of the positions and motions of sun-spots, but special investigations may well be undertaken with the aid of direct photographs. The important thing in all solar work is not merely to make observations of some single phenomenon, but to carry on two or three series of carefully correlated observations, so designed as to throw light on one another. For example, Mr. MAUNDER has recently found that the rotation periods of sun-spots in nearly the same latitude show differences as great as those encountered in passing from the equator to the highest latitude in which the spots are found. The cause of such differences may well be a subject of most careful investigation. The proper motions of spots, which are associated with their period of development, must be fully taken into account. We might also make the hypothesis, merely for the purpose of testing the question, that the rotation period of a sun-spot depends upon its level with respect to the photosphere. For this reason it would be desirable to investigate, in connection with the study of rotation, the question of the level of sun-spots. A simple means of doing this will be mentioned later. But it may be added here that the question of level raises other considerations, which should not be left out of account. It is probably worth while to investigate photographically the old Wilsonian hypothesis, since visual observations have proved so discordant in attempts to determine the relative widths of the preceding and following penumbra of spots at various distances from the center of the Sun. As a sun-spot is depressed below the level of the surrounding faculæ, the vexed question of the visibility of

the umbra near the limb may depend upon whether the faculæ are present or missing on the sides lying in the line of sight. It is quite possible that the temperature of the umbra may vary with its distance above the photosphere. Thus correlation between observations bearing on spot level and observations of spot spectra is desirable.

SPECTROSCOPY.

The spectroscopic study of solar phenomena has been greatly retarded through delay in adopting suitable instruments. The short-focus spectroscopes attached to equatorial telescopes are admirably adapted for visual observations, but in photography their linear dispersion is much too small to realize the full resolving power of the grating employed. In laboratory work, on the contrary, while the spectroscopes have been sufficiently powerful, they have usually been of the concave grating type, where astigmatism interferes seriously with the study of solar details, and the solar image on the slit of the spectroscope has been so small that the individual phenomena, in any event, could not be separately distinguished.

The preparation of a powerful spectrograph of the Littrow type is an extremely simple matter. A small slit, mounted on a short metallic tube, is supported immediately above a long narrow photographic plate. The wooden support for plate-holder and slit rests on a pier and forms the end of a long light tube of rectangular section, which is closed at its other end by the wooden support of the lens which serves at once for collimator and camera. The angular aperture of this lens is of course defined by that of the objective which forms the solar image on the slit, but if possible its focal length should be from ten to twenty feet. The rays, after being rendered parallel by the lens, fall upon a grating, which need not be larger than a four-inch (a much smaller one would do very useful work). The spectra should be photographed in the second, third, or fourth order, so as to give sufficient scale.

With such an instrument, new work of great value may be done. Even with a very small solar image, a photographic study of the solar rotation should yield results of great precision. HALM believes, from his spectroscopic work, that the rotation period varies with the solar activity. This is yet to be confirmed, but the question well deserves investigation.

There is some reason to think that the rotation period is not the same for different substances in the reversing layer. The iron lines, for example, may give values different from those obtained with the carbon lines. It is also interesting to inquire whether the "enhanced" lines of an element give the same period as the other lines in its spectrum.

Another interesting investigation, which does not require a large solar image, is the study of the radial velocity of the calcium vapor in the flocculi. It is only necessary to measure, with great precision, the wave-lengths of the H_2 and H_3 lines, corresponding to various points on the solar image. In this way the rise or fall of the calcium vapor in the flocculi can be ascertained. To be of the most service, this investigation should be carried on in conjunction with some other study of the flocculi.

The photographic study of sun-spot spectra offers a most promising opportunity. It is a very easy matter to photograph spot spectra in such a way as to record for study thousands of lines which are beyond the reach of visual observations. Nevertheless, this has been accomplished only recently, simply because spectrographs of suitable design have not previously been applied in this work. At the Solar Observatory on Mt. Wilson it has been found that in general the lines strengthened in spot spectra are strengthened in the laboratory when the temperature of the vapor is reduced, while the lines that are weakened in sun-spots are weakened in the laboratory under the same conditions. Thus it appears probable that the temperature of the spot vapors is below that of the reversing layer. This conclusion has been confirmed by the discovery in the spot spectrum of the flutings of titanium oxide. This molecule thus exists at the lower temperature of the sun-spot, but is broken up at the higher temperature of the reversing layer. The bearing of this result upon stellar spectroscopy will be seen when it is remembered that the flutings of titanium oxide form the principal feature of the spectrum of the third-type stars. It has also been found that *Arcturus* gives a spectrum resembling very closely the spectrum of a sun-spot. A further study of this question will require a large number of observations of spot spectra, with special reference to possible variations in temperature, as indicated by variations in the relative intensity of the spot lines. As already remarked,

the temperature of spots may also depend upon their level, and this possibility must be borne in mind.

WORK WITH THE SPECTROHELIOGRAPH.

It is perhaps commonly supposed that the spectroheliograph is necessarily an expensive instrument, out of reach of the average observer. As a matter of fact, however, a spectroheliograph capable of giving the best results can easily be constructed of materials ordinarily available in any observatory or physical laboratory. It is sufficient, for many purposes, to photograph only a narrow zone of the solar image. In this case small lenses will suffice for the collimator and camera, and small prisms for the optical train. The lenses and prisms may be mounted in wooden supports, on a wooden platform, rolling on four steel balls in V-shaped tracks. The motion of the instrument across the solar image may easily be produced by a simple screw, driven by a small electric motor. Such a spectroheliograph was used to good purpose at the Solar Observatory before the permanent instrument was completed.

Brief mention may be made of some of the numerous investigations possible with such an instrument. It has recently been found at the Solar Observatory that the dark hydrogen flocculi, photographed near the Sun's limb, are slightly displaced with reference to the corresponding calcium flocculi. In general, they lie nearer the limb. This probably indicates that the absorbing hydrogen clouds are on the average at a higher level than the brilliant calcium clouds. This subject deserves careful investigation, extending over a considerable portion of time. The type of spectroheliograph just referred to is as suitable for the purpose as any instrument that can be constructed. Another question, which seems to be somewhat more difficult to solve, is the actual difference in elevation of the calcium flocculi, as photographed in the H_1 and H_2 lines. Indeed, it is still a question as to how important a part the dense calcium vapor plays in determining the form of the H_1 flocculi. These objects resemble the faculæ so closely that they appear practically identical with them, though slight differences, which are apparently genuine, are occasionally found.

Another method of investigating this whole question of levels is afforded by the spectroheliograph. It will be remem-

bered that when the level of sun-spots was last under discussion reference was made to the relative radiation of the umbra and neighboring photosphere, corresponding to different distances from the center of the Sun. It was pointed out that when the spot approaches the limb its radiation decreases less rapidly than that of the photosphere. The natural conclusion was that the spot lies at a higher level than the photosphere, and thereby escapes much of the absorption produced by a comparatively thin layer of absorbing matter. Recent observations at Mt. Wilson have shown, however, that the proportion of violet light in sun-spots is much smaller than in the case of the photosphere. As it is known that the violet rays undergo much more absorption near the Sun's limb than those of greater wave-length, it is obvious that the light of the spot would suffer less absorption, even if it were at the same level as the photosphere. Thus the only proper method of investigating this question will be through the use of monochromatic light.

The spectroheliograph affords a simple means of accomplishing this. It is only necessary to make photographs of the spot and adjoining photosphere, corresponding to various distances from the Sun's center. The camera slit should be set on the continuous spectrum (not on a line), preferably in the violet or ultra-violet, since the change of absorption would be most felt in this region. In order to make photographic comparisons easily possible, the intensity of the photosphere should be reduced to approximately the intensity of the umbra, by means of a dark glass, mounted over the collimator slit, but not covering that part of the slit through which the light of the umbra passes. It is obvious that a large image of the Sun will be required in this work.

The spectroheliograph can be applied to other studies of absorption. The H_1 flocculi, for example, are reduced in brightness near the Sun's limb much more than the H_2 flocculi, presumably because the latter lie at a higher level. These differences can be studied photometrically on spectroheliograph plates made for the purpose. In the same way the H_1 flocculi can be compared with the faculæ. Since it is a question just what level is represented by the background (between the flocculi) in calcium, hydrogen, or iron photographs, the instrument should be arranged so as to permit photometric com-

parisons of this background with the photosphere, photographed with light from the continuous spectrum immediately adjoining the calcium, hydrogen, or iron line employed for the flocculi.

These new applications of the spectroheliograph have only recently occurred to me, and are mentioned because of their suitability for use with instruments containing prisms of ordinary height, capable of photographing only narrow zones of the solar image. Numerous other problems might be mentioned, such as the comparative study of H_1 , H_2 , and H_3 photographs, and of calcium, hydrogen, and iron images; the distribution of the flocculi in latitude and longitude; their varying area, as bearing on the solar activity and on terrestrial phenomena; and their motion in longitude, as measuring solar rotation. But limitations of time forbid more than a mere reference to work and methods the details of which are discussed elsewhere. My purpose has been accomplished if I have shown that with comparatively simple instrumental means any careful observer may secure important results. In much of this work it is desirable that investigators occupied with similar problems should co-operate with one another. The International Union for Co-operation in Solar Research was organized with this end in view. It has already inaugurated solar studies on a common plan in several different fields, and is preparing to extend the range of its activities in the near future.

NOTE ON THE DISTRIBUTION OF DOUBLE STARS
IN THE ZONE $+56^\circ$ TO $+90'$.¹

BY R. G. AITKEN.

The main object of the survey of the sky that has been in progress at the Lick Observatory for the past seven years is to accumulate data for a statistical study of the number and the distribution in space of the double stars whose combined magnitude is brighter than 9.1 of the B. D. scale, and whose angular separation is less than $5''$. This survey is now well advanced toward completion, so far as the sky area

¹ Read before the Astronomical and Astrophysical Society of America, New York, December, 1906.